JP-8+100LT: A LOW COST REPLACEMENT OF JPTS AS THE PRIMARY FUEL FOR THE U-2 AIRCRAFT?

THESIS

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Abstract

The Air Force currently spends approximately $10 million dollars annually on fuel support for the U-2 aircraft. The U-2 has used a jet fuel known as JPTS since the aircraft's development in the 1950's. JPTS is a specialty fuel used only by the U-2 and is produced by two oil refineries in the United States. As such, it has limited worldwide availability and costs over three times the per-gallon price of the Air Force's primary jet fuel, JP-8.

Recent research performed at the Air Force Research Laboratory Propulsion Directorate suggests that additives could be added to JP-8, which would make it a suitable low-cost replacement for JPTS. The additive-enhanced fuel has come to be known as JP-8+100LT.

This study analyzed two variables, logistics benefits and costs, and compared these variables for JPTS and JP-8+100LT to discover which one provides the most logistical benefits for the annual cost. The results of the analysis concluded that JP-8+100LT offers more benefits at significant cost savings.

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I. Introduction

General Issue

The U-2's mission of extended flight at high altitude requires a unique fuel with special attributes. Extremely low temperatures cause fuel to partially solidify and stop flowing sufficiently. To counter this, the fuel must have a higher viscosity than conventional fuels. Additionally, the fuel must have increased thermal stability due to the high temperature exposure incurred as the fuel approaches the engine. At altitude, the U-2 consumes fuel at 1/16 the rate of sea level combustion. The slow rate of flow subjects fuel to high temperatures and exposes it to the additional danger of thermal breakdown. Thus, the U-2's fuel must posses properties of enhanced cold flow as well as increased thermal stability.

The U-2's current fuel is officially entitled Thermally Stable Aviation Turbine Fuel but is more commonly referred to as JPTS. JPTS is an exotic fuel with a low freeze point, increased viscosity, and high thermal stability. Unfortunately, it is very expensive – at $3.25 per gallon, it costs over three times the price of conventional JP-8, the Air Force's primary jet fuel. The Air Force consumed 3.5 million gallon of JPTS in 1999 for a total cost of $11.3 million. An enhanced version of JP-8 modified to meet the needs of the U-2 could save the Air Force as much as $5 million annually throughout the life cycle of the aircraft.

Conventional JP-8 does not possess the thermal stability or cold flow requirements of the U-2. However, a recent advance known as JP-8+100 has increased thermal stability by 100 degrees F with an added price of only $.005 per gallon. JP-8+100 meets the U-2's thermal stability requirement and is now being used worldwide by all USAF fighter and trainer aircraft. Despite this, JP-8+100 does not have the low temperature characteristics needed for sustained flight at high altitude.

The Fuels Branch of the Air Force Research Laboratory at Wright-Patterson Air Force Base is conducting research to develop a low temperature additive for JP-8+100. The proposed new fuel, known as JP-8+100 LT, would meet U-2 fuel requirements at a substantially lower cost than JPTS. To date, several additives have been blended with JP-8+100 and tested in AFRL's low temperature laboratory. Significant enhancement of cold flow characteristics has been documented with several of the additives. The test results suggest that JP-8+100 may be modified to meet the low temperature requirements for use in the U-2.

Additional work needs to be performed to address important issues before cold-flow additives can be used in the field. Studies need to address the following areas of concern: additive optimization, additive/fuel systems compatibility, evaluation of additional additive candidates, cost savings analysis, field implementation, flight testing, engine testing, and the impact on the Air Force logistics community.

Research Objective

The primary purpose of this research is twofold. The first objective is to quantify the benefits of the two fuels and determine the logistics impact of a conversion. The

second objective is to estimate the costs of the two to determine if JP-8+100LT offers potential cost savings.

Research Question

The overall research question to be answered in this study is as follows: Is JP-8+100LT a suitable replacement for JPTS with respect to logistical benefits and cost?

Investigative Questions

In order to arrive at an answer for the overall research question, the following investigative questions must be answered.

1. What are the logistical benefits of JP-8+100LT and JPTS?
2. Does JP-8+100LT offer more benefits than JPTS?
3. What are the costs associated with the use of JP-8+100LT and JPTS?
4. Does JP-8+100LT offer cost savings over JPTS?
5. How does JP-8+100LT compare to JPTS in an overall value comparison?

Assumptions/Limitations

The chemical properties of fuel and their interactions with aircraft subsystems are beyond the scope of this research. As such, performance issues will not be explored. For the purposes of this study, it will be assumed that additive-enhanced JP-8 (JP-8+100LT) performs suitably with the U-2 aircraft and all affected fuel subsystems.

II. Literature Review

Introduction

This chapter presents a summary of the development of aviation turbine (jet) fuel and the evolution of types of turbine fuel used by the Air Force throughout history. This background material will prepare the reader for the introduction of contemporary aviation fuel including the fuel currently used by the U-2 and its potential replacement.

Origins of Jet Fuel

Dr. Hans Von Ohain of Germany developed the first successful turbine (jet) engine. His aircraft, the Heinkel He 178, first flew on 27 August 1939. Because of its use in all piston aircraft engines at the time, Von Ohain chose gasoline as the first fuel. Sir Frank Whittle of Great Britain was another jet engine pioneer during the 1930's and 1940's. Whittle developed an engine that first took flight on a Gloster E28/32 aircraft on May 14, 1941. This time the fuel of choice was kerosene, again due to availability.

The first jet fuel used in the United States was aviation gasoline (AVGAS) and all future generations of turbine fuel have evolved from basic chemical properties of AVGAS. However, it was noticed that the high volatility of gasoline produced "vapor lock" in turbine engines at high altitude. Since this discovery, aviation jet fuels have undergone many modifications that continue today. (Harrison, 1999: 1-3)

Air Force Jet Fuels (Martel 1987: 1-13)

Since the first use of gasoline as jet engine aviation fuel, there have been a number of jet fuels the Air Force has used. As fuel technology evolved, it was

determined that turbine engines could use a wider variety of fuels than their diesel and gas engine cousins. However, jet engine performance tends to vary greatly with different chemical and physical fuel properties. This led to the development of strict military specifications that Air Force fuels had to meet to ensure proper performance throughout all stages of flight. In 1944, Jet Propellant 1 (JP-1) was the first fuel developed in accordance with these specifications. Since then, nine more JP classes have been developed through better understanding of fuels technology to meet the demand of advancing aircraft and engine fuel system requirements.

JP-1 was the first jet fuel made in the United States. It was kerosene-based and very similar to and influenced by the current British fuel being used in their early jet engines. The similarity of the fuels was due in part to the fact that United States used British engines as models in jet engine development. JP-1 production was short lived, however, and the US began to develop its own jet engine technology as the evolution of Air Force jet fuels began.

JP-2 was developed in 1945 using a wide-cut distillation process that included both gasoline and kerosene. It was produced to increase fuel availability due to the limited quantity of JP-1. Although JP-2 was easily produced, it too was short-lived due its inability to meet flammability specifications and was only used experimentally.

The Air Force developed its second operational fuel in 1947. JP-3 was a wide-cut fuel similar to JP-2, but had higher vapor pressure characteristics that improved low temperature starting and high altitude relight. As with the previous fuels, problems arose which limited its production. This time, the problem was vapor lock at high altitude.

JP-4 entered service in May 1951 and became the Air Force's primary jet fuel until its replacement with JP-8. It was created using the same wide-cut distillation process previously used in JP-2 and JP-3 production with a composition of 60 percent gasoline and 40 percent kerosene. JP-4 retained the starting and high altitude relight characteristics as JP-3 with a significant reduction in boil off limitations.

JP-5 was developed for the Navy in 1952 as a replacement for the contemporary commercial aviation gasoline. The aviation fuel contained lead that was sticking to engine parts causing a variety of engine problems. It was originally developed as an kerosene additive that was to be blended with the aviation gasoline to increase the flash point. However, the Navy discovered pure JP-5 met the strict shipboard storage safety requirements in addition to meeting performance requirements. As such, it became the Navy's primary jet fuel.

JP-6 was specifically developed for the short-lived XB-70. The fuel was very similar to JP-5 but had a lower freezing point and increased thermal oxidative stability which overcame JP-5's tendency of to foul injector nozzles. The production of JP-6 was halted when the XB-70 program was canceled.

JP-7 was developed in 1970 to replace the experimental fuel PF-1 that was being used for the SR-71. The SR-71's unique role with cruising speed at over mach 3 at very high altitudes called for a unique fuel with special properties. JP-7 met these requirements with a very low vapor pressure and improved thermal oxidative stability. Unlike many previously developed fuels, it was not produced by means of crude oil distillation. JP-7's unique production began with mixing fuel stocks with low impurities.

Despite the low impurities, the resulting fuel was low in required lubricants and required the addition of additives.

JP-8 was developed in the 1970's to replace JP-4. A negative characteristic of wide-cut distillate fuels such as JP-4 is high volatility (ease of ignition). This high volatility characteristic contributed to higher Air Force aircraft losses during the Vietnam Conflict when compared to Navy losses that used lower-volatility JP-5 fuel. Post-crash fires for aircraft using JP-4 were considerably higher than aircraft using kerosene blends. Additionally, ground handling and storage is safer with lower volatility kerosene-based fuels. Bases worldwide began converting to JP-8 in the late 1970's and the conversion was complete in 1990's, although most bases had converted in the 1980's. It is currently both the NATO and USAF primary Jet Fuel. (Maurice 1999: 6-7)

JP-8+100 (Harrison 1996: 173-174, 178)

With advancing aviation technology, aircraft fuel usage in non-combustion purposes has become increasing commonplace. An important instance of this is fuel's role as coolant for internal components during flight. As aircraft components become more advanced and produce more heat, the role of fuel as a heat sink increases. Advanced aircraft are also more fuel-efficient which leads to less available fuel to cool the higher sources of heat. This results in fuel being exposed to higher temperatures and thermal breakdown. As fuel is subjected to temperatures above its thermal satiability limit, it breaks down leaving damaging varnishes and gums on engine components. Thermal instability products cause poor engine performance and expensive recurring maintenance.

Current Air Force fighter and trainer aircraft expose fuel to thermal breakdown conditions, and as a result, suffer from significant maintenance downtime associated with thermal instability product residue. In particular, Air Force aircraft suffering from thermal stability related problems experienced a 53% increase in unscheduled engine removals (UER), a 53% increase in mechanical faults, and a 114% increase in anomalies.

These problems led the Air Force in 1989 to initiate a research program to increase the thermal stability of JP-8, the Air Force's primary fuel. This program culminated with the introduction of a new additive for JP-8 that increased its thermal stability by 100 degrees Fahrenheit. The additive, produced by BetzDearborn Corporation, is known as 8Q462 or Aeroshell Performance Additive 101. It is injected into normal JP-8 at a rate of 256 parts per million – approximately 1 quart per 1000 gallons of fuel. Once injected into the fuel the resulting mixture is known as JP-8+100.

In addition to its thermal stability properties, the fuel was found to have the unexpected side effect of removing existing thermal instability products in engines previously run on normal JP-8. In a study of engine maintenance trends at Langley AFB, VA, Air Force F100 engines were found to have a 17% decrease of UER, a 38% reduction in anomalies, and a 48% decrease in mechanical faults after converting to JP-8+100. JP-8+100 is now the primary fuel for all fighter and trainer aircraft worldwide. The conversion to JP-8+100 resulted in an $80 million dollar savings in maintenance costs for an additional additive cost of approximately $1 per 1000 gallons of fuel.

The U-2 and JPTS (McCoy, 1980: 336-337)

The U-2 “spy plane” provides around-the -clock, all-weather, high altitude surveillance of any location in the world in direct support of U.S. and allied forces. It provides crucial intelligence to allied commanders through a wide range of scenarios from peacetime to war. It also provides intelligence in support of disaster relief and humanitarian missions. It is a single-seat, single-engine reconnaissance aircraft. Its long, straight wings give the U-2 glider-like characteristics. It is capable of carrying a large variety of sensors and cameras, and is an extremely reliable aircraft with a high mission completion rate. Because of the high altitudes the U-2 operates in, the pilot wears a pressure suit / helmet ensemble.

Developed by the now famous Lockheed "Skunk Works", the U-2 was originally designed as a high altitude reconnaissance platform to penetrate the airspace of the Soviet Union in the mid-1950s. The U-2’s first flight took place August 4, 1957 -- just 8 months after the production began. On May Day, 1960, Francis Gary Powers was shot down in his U-2 over the Soviet Union and put on public trial. During the Cuban missile crisis, another U-2 was shot down over Cuba, but not before previous missions photographed the installation of Soviet ICBMs. Most of the U-2 fleet today was made in the mid-late 1980s.

The U-2 conducted extensive reconnaissance operations during Desert Shield and Desert Storm – U-2s gathered over 90% of the intelligence during the conflict. With its wide range of sensor packages, the U-2 captured high-resolution photographs, and performed a wide range of intelligence gathering and radar mapping operations. U-2 operations greatly enhanced Allied Force’s strategic decisions. Decision-makers ranging

from the President to field commanders used information gathered by the U-2 to locate targets, identify enemy troop strength, and make battle damage assessments. The 43-year-old U-2 is the only aircraft in the Air Force inventory that flies operational missions every day throughout the year. As new situations arise the U-2 is deployed to provide the United States with the most accurate and up-to-the-minute intelligence.

In order to perform its specialty mission, the U-2 operates at altitudes above 70,000 feet – twice as high as commercial airliners. These flight conditions expose the U-2's fuel, which is stored in the wings, to extremely low temperature conditions. Ironically, the fuel is also subjected to high heat loads as it approaches the engine. While at cruising flight, the U-2's engine is running very slowly. The fuel flow during this period is 1/16 of the flow at sea level. Consequently, the fuel is subjected to heat stress for a significantly longer time than in conventional aircraft. These demanding conditions require a fuel that embodies high thermal stability as well as properties to resist freezing while in the wings. JPTS, the U-2's current fuel, meets these requirements. But due to the fuel's special characteristics, JPTS is available only from a small number of manufacturers in the United States and must be pre-positioned throughout the world. JPTS is transported by tank truck or railroad tank car within the CONUS; by sealift in tanker vessels to locations overseas; or by airlift in 55-gallon drums. The scarcity of the fuel may be a limiting factor in worldwide U-2 operations. For example, during desert storm JPTS was available only from RAF Akrotiri, Cyprus, and Torrejon AB, Spain. In contrast, JP-8 was available locally in Saudi Arabia. In order to support U-2 operations, JPTS had to be airlifted in 55-gallon drums and stored in 50,000-gallon storage bladders.

JP-8+100 LT (Obringer, 1999: 1246-1249, 1251)

As stated earlier, the purpose of this work is to identify the impact of an alternate fuel for the U-2. As we have seen, the U-2 requires a fuel that has high thermal stability as well as cold flow properties. JPTS meets these requirements, but at $3.25 a gallon, it is over three times the cost of standard JP-8 at $1.01 per gallon. An enhanced version of JP-8 that meets the U-2's requirements would be less costly and more plentiful than JPTS. To achieve this, JP-8 would have to be modified to meet both the thermal stability and cold flow requirements. With its thermal stability additive, JP-8+100 meets the first requirement. The lone missing ingredient is an effective cold flow additive.

The Air Force currently uses cold-flow additives in diesel ground fuels to increase their flow ability at low temperatures. The Fuels Branch of the Air Force Research Laboratory has recently finished a risk reduction/feasibility study to determine if similar additives could be used in aviation fuel to improve low-temperature flow properties. The one-year study identified an additive that successfully increases the cold flow properties of JP-8 based fuel that meets low-temperature requirements of the U-2. The findings of the U-2 Fuel Conversion Study demonstrated the ability of producing an additive for JP-8+100 which meets both thermal stability and cold flow requirements. A number of flow-enhancing additives were tested with JP-8 in a laboratory and it was found that several met or exceeded the requirement of the U-2. This experimental JP-8-based fuel is known as JP-8+100 LT. (Obringer 1999: 1251)

To create JP-8+100 LT, the cold-flow additive will be injected into JP-8 simultaneously with the +100 thermal stability additive using a second pump. This could

be accomplished at the fillstand as the truck is being filled, or at the truck with a mobile injector as the aircraft is refueled

Summary

While JPTS meets the demands of the U-2, current research indicate that additives could be used with common fuel to meet or exceed the specifications of JPTS. This new fuel, known as JP-8+100LT, is an additive-enhanced version of the Air Force's primary jet fuel, JP-8.

III. Methodology

Introduction

The purpose of this chapter is to explain the methods used to answer the investigative questions introduced in Chapter 1. The goal of the investigative questions is to determine the logistical benefits and costs of the two fuels. Once identified, the benefits and costs will be used to perform a cost-benefit analysis that will answer the overall research question of this study.

Cost benefit analyses traditionally consider at least three viable alternatives. However, the analysis performed in this study considers only two alternatives since JP-8+100LT is the only fuel available to replace JPTS. Despite the limited number of alternatives, the methods presented in this chapter include all functions normally performed in a traditional cost benefit analysis.

General Approach

In general, this study is directed at examining the attributes of JPTS and JP-8+100LT to determine the most suitable and cost effective fuel for the U-2 aircraft. To that end, the remainder of this study concentrates on the assessment of benefits and costs. Figure 1 depicts the Value Hierarchy developed to guide the analysis. The Value Hierarchy used in this study was developed with the help of SMSgt Clifford Cunningham, Fuels manager at Cannon AFB, and ACC's Fuels Superintendent of the Year for 2000. The hierarchy depicts the three cost components considered in this study, as well as the four critical areas of Air Force fuel support.

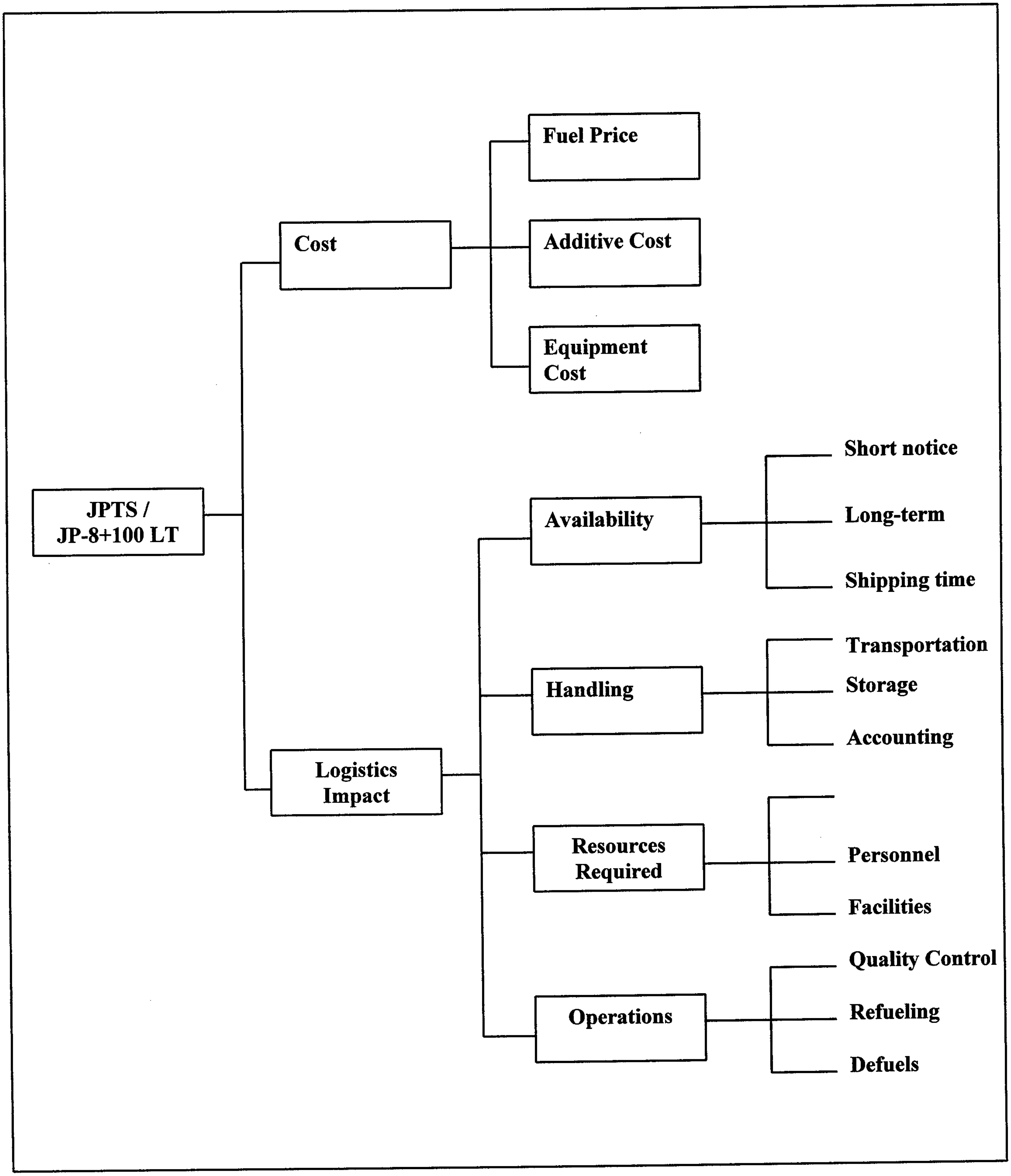

Figure 1. JPTS vs. JP-8+100LT Value Hierarchy
(Adopted from Kirkwood, 1997:26)

The Analysis will be conducted in three parts. First, the logistics benefits of each fuel system will be quantified through the analysis of a survey (Appendix A) distributed to experts throughout the Air Force fuels community.

Second, costs of both fuels will be presented based on the net present value of estimated future fuel prices and consumption. In the case of JP-8+100LT, the cost of the required additive and additional equipment will be included.

Finally, a cost-benefit analysis (CBA) will be performed for the periods of five, ten, and twenty years using converted cost and benefit data. The numerical value obtained from this analysis will reflect each fuel's desirability with respect to logistics impact and expense.

The following sections provide detailed information about each of the three steps of the analysis.

Determining Benefits

Benefits are the capabilities, services, and qualities of each fuel and its associated support system. Benefits may be positive or negative in nature. In this study, degradation in capability offered by a fuel is still considered a 'benefit' despite its negative effect. Thus, a benefit must be viewed as an attribute without regard to its desirability. The method used in this study to determine and quantify benefits has been adopted from a multi-objective value analysis approach as outlined in Craig W. Kirkwood's book "Strategic Decision Making". (Kirkwood 1997: 53-85)

Identification of Benefits. The logistics benefits offered by both JPTS and JP-8+100LT have been identified using common categories. The four categories of benefits used in this study are a reflection of four critical areas of fuel support: Availability, Handling, Resources Required and Operational Efficiency. The measurement criteria for each benefit have been outlined in Figure 2, and are based on the Value Hierarchy in Figure1.

Benefit	Measurement Criteria
Availability	Short-notice availability Availability in remote locations Order shipment time
Handling	Ease of transporting Ease of storing Ease and accuracy of accounting
Resources Required	Personnel requirements Facility requirements Equipment requirements
Operational Efficiency	Ease and accuracy of quality control Efficiency of refueling Ease of handling defuels

Figure 2. Benefits and Measurement Criteria

Measuring Benefits. The benefits examined in this study are intangible in nature since they are not inherently numerical. Thus, it is necessary to quantify the benefits offered by the alternative fuels. A fuel's contribution in each benefit category is measured using the following five-point scale:

Table 1. Benefit Measurement Scale

1.	Provides Maximum Benefits	(4 points)
2.	Provides Some Benefits	(3 points)
3.	Provides no Benefits – Status Quo	(2 points)
4.	Provides Some Negative Benefits	(1 point)
5.	Provides Maximum Negative Benefits	(0 points)

In this study, JPTS automatically receives the score for the status quo (2 points) in each benefit category since it is the fuel currently being used. JP-8+100LT will be assigned a subjective score for each benefit category.

A range of values from 0 to 4 was adopted because it reflects a score that is in proportion to the desirability of a selected benefit. This system was chosen over a scale that ranged in value from 2 to –2 because such a scale would assign a score of 0 to the status quo (JPTS). It was necessary to establish a score for JPTS in order to perform some of the calculations in the cost-benefit analysis.

Data Collection. A survey (Appendix A) was distributed to determine the benefits of JP-8+100LT. The test group was a wide variety of personnel within the fuels community with in-depth knowledge of fuels operations -- particularly operations involving the U-2, JPTS, and JP-8+100. These stakeholders identified, in their opinion, a score and relative ranking for each of the benefit categories based on the measurement criteria in Table 1.

A total of 30 surveys were distributed to individuals in the organizations below. The participants were chosen for their expertise in refueling operations involving the U-2. In all, 21 surveys were returned (n=21). These surveys were used as the basis for the benefit analysis performed in Chapter 4. The raw values from the surveys are presented in Appendices B and C.

1. HQ USAF Supply/Fuels Policy Division. Two representatives from this office were surveyed.

2. The Air Force Petroleum Office. Two representatives from this office were surveyed.

3. Applicable MAJCOM LGSFs. Two representatives from each of the following MAJCOM LGSF offices were surveyed. In all, ten MAJCOM representatives were surveyed.

Air Combat Command

Air Force Materiel Command

Air Force Reserve Command

Air Force Space Command

Pacific Air Forces

4. Installation Fuels Flight Commanders and Superintendents. The Fuels Management Team (or civilian equivalents) of each Air Force Installation that conducts JPTS/U-2 operations were surveyed. Two individuals from each of the following installations were surveyed.

Anderson AFB, Guam (PACAF)

Bealle AFB, CA	(ACC)
Hickam AFB, HI	(PACAF)
Kadena AB, Japan	(PACAF)
Osan AFB, Korea	(PACAF)
Patrick AFB, FL	(AFSPC)
Robbins AFB, GA	(AFMC)
Westover ARB, MA	(AFRC)

The values obtained from the surveys reflect JP-8+100LT's ability to meet Air Force needs as determined by those who know best – The men and women of the Air Force POL community who oversee, manage, evaluate, and conduct refueling operations on a daily basis worldwide.

Scores. Recipients rated JP-8+100LT's expected contribution in each of the four benefit categories using the scale in Table 1. Each rating is converted into the corresponding score. The average of all submitted ratings was used to determine the final Average Score (AC) for each benefit as illustrated in Table 2.

Table 2. Example Benefit Scores

Benefit	Reviewer 1 Score	Reviewer 2 Score	Reviewer 3 Score	Reviewer 4 Score	Reviewer Average Score (AC)
A	0	1	0	0	0.25
B	4	4	4	4	4.00
C	4	3	3	4	3.50
D	3	3	2	3	2.75

Weights. In order to account for the differing importance among the categories, survey recipients assigned a weight to each benefit. A percentage system was used to determine each benefit category's relative importance. Each survey participant allocated 100 points among the four categories. The averages of each category's submitted weights were used as the final Average Weight (AW).

Table 3. Example Benefit Weights

Benefit	Reviewer 1 Weight	Reviewer 2 Weight	Reviewer 3 Weight	Reviewer 4 Weight	Reviewer Average Weight (AW)
A	0.10	0.25	0.10	0.05	0.125
B	0.20	0.25	0.20	0.20	0.213
C	0.30	0.25	0.10	0.35	0.250
D	0.40	0.25	0.50	0.40	0.388

Determining the Overall Benefit Rating (BR). The ultimate goal of the benefit analysis is to arrive at a single value that represents the fuel's desirability in terms of logistics impact. Once the scores and weights have been determined, the overall Benefit Rating is calculated in two steps.

First, each benefit's Average Score (AC) is multiplied by it's Average Weight (AW) to arrive at weighted scores. An example of this procedure is provided in Table 4.

Table 4. Example Weighted Scores

Benefit	Average Score (AC)	Average Weight (AW)	Weighted Scores (AC)*(AW)
Alternative			
A	0.25	0.125	0.031
B	4.00	0.213	0.850
C	3.50	0.250	0.875
D	2.75	0.388	1.066
Baseline			
A	2.00	0.125	0.250
B	2.00	0.213	0.425
C	2.00	0.250	0.500
D	2.00	0.388	0.775

Second, the sum of the weighted scores is used as the Overall Benefit Rating (BR) as illustrated in Table 5. The Overall Benefit Rating is the value attributed to a fuel's total benefit contribution.

Table 5. Example Overall Benefit Ratings (BR)

	Benefit A Weighted Score	Benefit B Weighted Score	Benefit C Weighted Score	Benefit D Weighted Score	Overall Benefit Rating (BR) (Sum A:D)
Alternative	0.031	0.850	0.875	1.066	2.822
Baseline	0.250	0.425	0.500	0.775	1.950

Estimating Costs

The per-gallon price of military fuel includes all costs incurred in production and delivery to the each Air Force installation. Thus, the per-gallon costs of both fuels in this study serve as the base for all cost calculations.

Overall fuel costs are presented for the periods of five, ten, and twenty years. The final cost figures are arrived at through estimating future prices and consumption then discounting overall annual costs to determine net present values. The cost estimation methods used in the study are based on the preferences of the cost-benefit guidance set forth in "Cost-Benefit Analysis Guide for NIH IT Projects". (Lagas, 2000)

Estimating Future Prices. Future fuel prices were estimated by determining the prices for each fuel during the past five years, calculating the percent change from year to year, then taking the average of these percent changes. This process will be performed for both fuels as illustrated in Table 6. The resulting percent annual increase value will be used to determine the annual cost increase for each fuel throughout the life cycle. Separate cost calculation will be performed for each fuel.

Table 6. Example Average Fuel Price Increase

	1997	1998	1999	2000	2001
Price per gallon	$ 1.00	$ 1.07	$ 1.15	$ 1.23	$ 1.27
Increase		$ 0.07	$ 0.08	$ 0.08	$ 0.04
Avg. Increase					$ 0.07

For the case in the example above, a $0.07 annual increase would be used to determine future annual fuel costs.

Estimating Future Demands. Similar to the method to estimate future fuel prices, future fuel consumption is estimated by determining the consumption during the past five

years, calculating the percent change from year to year, then taking the average of these percent changes. Unlike the estimation of fuel prices, only the consumption of JPTS is of interest since it estimates the fuel consumption of the U-2.

Table 7. Example Average Consumption

	1997	1998	1999	2000	2001
Fuel Usage	300,000	302,000	302,000	303,000	303,000
% Change		0.007	0.000	0.003	0.000
Average %					0.002

In the example above, the average annual increase would be estimated at 0.2%.

Estimating Overall Annual Fuel Costs. The estimated overall annual costs are figured by multiplying the estimated price by the estimated consumption as illustrated in Table 8.

Table 8. Example Annual Costs (Based on a 6.2% annual price increase and 0.2% annual consumption increase)

Year	Estimated Price per gallon	Estimated consumption	Estimated Annual Cost
2001	$ 1.35	303,606	$ 409,868
2002	$ 1.43	304,213	$ 436,150
2003	$ 1.52	304,822	$ 464,118
2004	$ 1.62	305,431	$ 493,879
2005	$ 1.72	306,042	$ 525,549

Discounting Costs. After the costs have been identified for each year, they are converted by discounting future dollar values, thus transforming future costs to their net

present value. The net present value (or discounted value) is calculated with the following formula:

$$P = F\ (1/(1+I)^n)$$

P = Present Value, F = Future Value, I = Interest Rate, and n = number of years

Discount Factors. Using this formula in the previous section, discount factors have been developed in Table 9 for use in determining net present value.

Table 9. Discount Factors (based on a 4.1% interest rate)
In the formulas below, I = interest rate 0.041
n = number of years, ^ indicates that the
number following it is an exponent.

Year	Year-end Discount Factors 1/(1+I)^n	Mid-year Discount Factors 1/(1+I)^(n-.5)	Year-start Discount Factors 1/(1+I)^(n-1)
1	0.9606	0.9801	1.0000
2	0.9228	0.9415	0.9606
3	0.8864	0.9044	0.9228
4	0.8515	0.8688	0.8864
5	0.8180	0.8346	0.8515
6	0.7858	0.8017	0.8180

Since costs occur steadily throughout the year, Mid-year Discount Factors will be used in this study. An interest rate of 4.1 percent was chosen in accordance with OMB guidance set forth in Circular No. A-94, Revised: Guidance and Discount Rates for Benefit-Cost Analysis of Federal Programs. (OMB, 2000)

Annual Discounted Costs. The gross annual fuel costs are first figured using the estimated fuel prices and consumption levels determined in the previous sections as shown in Table 10.

Table 10. Example Annual Costs (Based on a 6.2% annual price increase and a 0.2% annual consumption increase)

Year	Estimated Price per gallon	Estimated consumption	Estimated Annual Cost
2001	$ 1.35	303,606	$ 409,868
2002	$ 1.43	304,213	$ 436,150
2003	$ 1.52	304,822	$ 464,118
2004	$ 1.62	305,431	$ 493,879
2005	$ 1.72	306,042	$ 525,549

The discounted values may then be calculated using the discount factor as illustrated in Table 11. The discounted costs will be used to determine the overall costs of each fuel.

Table 11. Example Annual Discounted Costs

Year	Annual Fuel Cost	Startup Costs	Total Annual Costs	Discount Factor	Annual Discounted Cost	Cumulative Discounted Costs (CDC)
1	$ 409,868	$ -	$ 409,868	0.9801	$ 401,716	$ 401,716
2	$ 436,150	$ -	$ 436,150	0.9415	$ 410,639	$ 812,355
3	$ 464,118	$ -	$ 464,118	0.9044	$ 419,761	$ 1,232,115
4	$ 493,879	$ -	$ 493,879	0.8688	$ 429,085	$ 1,661,200
5	$ 525,549	$ -	$ 525,549	0.8346	$ 438,616	$ 2,099,817

In the example above, startup costs have not been included. The analysis in Chapter 4 includes equipment startup costs and additive costs.

Cost Benefit Analysis

While the costs of this study can be quantified in dollar terms, the benefits cannot. As a result, alternatives cannot be evaluated using present values of costs and benefits. However, valid estimations are made using a combination of quantified benefit values and dollar values.

Using the benefit and cost data, a cost-benefit analysis may now be performed. First, a simple relative value comparison is performed comprised of the cost and benefit values. Since this simple comparison does not always indicate a clear winner, cost estimates are converted to relative values that are comparable to the values for the benefits. Finally, a benefit-to-cost ratio is performed to determine the most cost-effective alternative. The cost-benefit analysis methods used in this study have been adopted from the guidance of "Cost-Benefit Analysis Guide for NIH IT Projects". (Lagas, 2000)

Relative Value Comparison. This is the simplest way of alternatives. As shown in Table 12, costs and benefits may be directly compared.

Table 12. Relative Benefit Comparison

Fuel	Cumulative Discounted Cost (CDC)	Benefit Rating (BR)
5 Years		
Alternative Fuel	$ 850,925	2.82
Baseline Fuel	$ 2,099,817	1.95
10 Years		
Alternative Fuel	$ 1,486,493	2.82
Baseline Fuel	$ 4,443,446	1.95
20 Years		
Alternative Fuel	$ 2,591,124	2.82
Baseline Fuel	$ 9,978,667	1.95

In each of the cases above, the Alternative Fuel is the clear winner since it provides more benefits at a lower cost. However, in many situations benefits increase with higher cost and a clear winner is not evident. Further analysis is necessary in such an instance.

Converting Benefits and Costs. In order to perform further analysis, cost estimates are converted to relative values that are comparable to those of the benefits. In the example in Table 13, costs have been divided by 100,000 and the Overall Benefit Ratings have been multiplied by 100. These values provide the comparable values needed for the next step of analysis.

Table 13. Conversion Table

Fuel	**Cumulative Discounted Cost (CDC)**	**Conversion factor 1/100000 (CF1)**	**Converted Cost (CC)**	**Benefit Rating (BR)**	**Conversion factor 100 (CF2)**	**Converted Benefit (BRxCF)**
5 Years						
Alternative	$ 850,924.51	0.00001	8.51	2.8219	100	282.19
Baseline	$ 1,959,531.84	0.00001	19.60	1.9500	100	195.00
10 Years						
Alternative	$ 1,486,493.40	0.00001	14.86	2.8219	100	282.19
Baseline	$ 3,865,846.68	0.00001	38.66	1.9500	100	195.00
20 Years						
Alternative	$ 2,591,123.91	0.00001	25.91	2.8219	100	282.19
Baseline	$ 7,524,567.15	0.00001	75.25	1.9500	100	195.00

Overall Value Comparison. Finally, a benefit-to-cost ratio may be calculated using the converted values as shown in Table 14. The benefit-to-cost analysis provides a value assessment with respect to both logistics benefit and cost. This study will use the value from the benefit-to-cost analysis to determine the fuel more suitable for use as the primary fuel of the U-2 aircraft.

Table 14. Relative Value Comparison

Fuel	Converted Cost (CC)	Converted Benefit (CB)	Benefit To Cost Ratio CB/CC	Percent Improvement
5 Years				
Alternative	8.51	26.63	3.13	307%
Baseline	19.60	20.00	1.02	-
10 Years				
Alternative	14.86	26.63	1.79	346%
Baseline	38.66	20.00	0.52	-
20 Years				
Alternative	25.91	26.63	1.03	387%
Baseline	75.25	20.00	0.27	-

In the example case above, the Alternative fuel is again the winner with an increasing edge on the Baseline fuel with longer time horizons.

Summary

This chapter addressed the methodology for the forthcoming data analysis in the next chapter. The procedures used to quantify benefits were explained as well as the methods for estimating discounted annual costs. Finally, the methods used to perform a cost benefit analysis were explained.

IV. Analysis and Results

Introduction

The analysis procedures described in Chapter 3 were established with the express purpose of answering the investigative and overall research questions of this study. To review, the investigative questions were:

1. What are the logistical benefits of JP-8+100LT and JPTS?
2. Does JP-8+100LT offer more benefits than JPTS?
3. What are the costs associated with the use of JP-8+100LT and JPTS?
4. Does JP-8+100LT offer cost savings over JPTS?
5. How does JP-8+100LT compare to JPTS in an overall value comparison?

First, questions 1 and 2 will be addressed in the following Benefit Analysis section. Second, questions 3 and 4 will be answered in following Cost Analysis section. Finally, the following Cost Benefit Analysis will address question 5.

Benefit Analysis Results

Survey Scores. Table 15 summarizes the scores submitted by the survey respondents for each benefit category. A complete breakdown of all submitted scores is contained in Appendix B.

Table 15. Average Survey Scores

Availability	Handling	Resources Required	Operational Efficiency
3.3810	2.8571	2.0476	2.3333

As explained in Chapter 3, the survey recipients evaluated only JP-8+100LT in their scoring. JPTS automatically received a baseline score of 2 for each benefit category since it is the status quo.

The survey score results indicate that JP-8+100 LT is perceived to offer more benefits than JPTS in all categories. The Availability and Handling scores are significantly higher than the baseline (JPTS) score. However, the Handling and Operational Efficiency scores are only marginally greater than the baseline score.

Survey Weights. Table 16 summarizes the weights submitted by the survey respondents for each benefit category. The survey results indicate that most value is placed on Resource Requirement and Availability, followed by Handling and Operational Efficiency. A complete breakdown of the submitted weights may be found in Appendix C.

Table 16. Average Survey Weights

Availability	Handling	Resources Required	Operational Efficiency
0.2976	0.2048	0.3143	0.1833

Overall Benefit Rating. Before calculating the Overall Benefit Rating, weighted scores were calculated for each benefit category. As outlined in Chapter 3, the scores and weights for each benefit are multiplied to arrive at the weighted scores in Table 17. The resulting weighted scores

Table 17. Weighted Scores

Benefit	Average Score (AC)	Average Weight (AW)	Weighted Scores (AC)*(AW)
JP-8+100LT			
Availability	3.381	0.298	1.006
Handling	2.857	0.205	0.585
Resources Required	2.048	0.314	0.644
Operational Efficiency	2.333	0.183	0.428
JPTS			
Availability	2.000	0.298	0.595
Handling	2.000	0.205	0.410
Resources Required	2.000	0.314	0.629
Operational Efficiency	2.000	0.183	0.367

Next, the sum of the weighted scores was used to calculate the Overall Benefit Rating as shown in Table 18.

Table 18. Overall Benefit Ratings (BR)

	Availability Weighted Score	Handling Weighted Score	Resources Weighted Score	Operations Weighted Score	Overall Benefit Rating (BR)
JP-8+100LT	1.006	0.585	0.644	0.428	2.663
JPTS	0.595	0.410	0.629	0.367	2.000

As the above table illustrates, JP-8+100 received a higher Overall Benefit Rating, which indicates that it is the preferred fuel of the survey recipients. This analysis answers the first two investigative questions of this study: After the benefits of each fuel have been quantified, JP-8+100LT emerges as the fuel that seems to offer the most benefits in terms of logistics.

Cost Analysis Results

The following section concentrates on determining the costs JP-8+100LT and JPTS. Annual costs were first estimated, then these costs were discounted to determine net present value.

Average Annual Increases and Current Prices. The costs of both fuels are based on estimated future prices and consumption. Tables 19 and 20 present fuel prices from the past five years. The JP-8 price data was collected from the Defense Energy Support Center (DESC) on their website (http://www.desc.dla.mil). The consumption data for JPTS was collected from the JPTS functional manager (Westhausen, 2000).

Table 19. JPTS Annual Per-Gallon Prices and Average Annual

	1997	1998	1999	2000	2001
Price per gallon	$ 2.71	$ 2.83	$ 2.96	$ 3.12	$ 3.25
Increase		$ 0.12	$ 0.13	$ 0.16	$ 0.13
Avg. Increase					$ 0.14

Table 20. JP-8 Annual Per-Gallon Fuel Prices and Average Annual

	1997	1998	1999	2000	2001
Price per gallon	$ 0.77	$ 0.91	$ 0.83	$ 0.96	$ 1.01
Increase		$ 0.14	$ (0.08)	$ 0.13	$ 0.05
Avg. Increase					$ 0.06

As shown above, the average per-gallon price increases for JPTS and JP-8 were 7.3% and 7.6% respectively. Since only five years of price data were available, these figures were to estimate the future fuel prices in Tables 21 and 22. This method was chosen in the absence of a more accurate estimation involving more data.

Table 21. Estimated JP-8+100LT Annual Gross Costs
(Based on a $0.06 annual price increase and no annual consumption increase)
Price includes $0.005 per gallon additive cost

Year	Estimated Price per gallon	Estimated consumption	Estimated Annual Cost	Startup Costs	Total Annual Gross Cost
2001	$ 1.01	3,109,883	$ 3,140,982	$ 300,000	$ 3,440,982
2002	$ 1.08	3,109,883	$ 3,343,124	$ 300,000	$ 3,643,124
2003	$ 1.14	3,109,883	$ 3,545,267	$ 300,000	$ 3,845,267
2004	$ 1.21	3,109,883	$ 3,747,409	$ 200,000	$ 3,947,409
2005	$ 1.27	3,109,883	$ 3,949,551	$ -	$ 3,949,551
2006	$ 1.34	3,109,883	$ 4,151,694	$ -	$ 4,151,694
2007	$ 1.40	3,109,883	$ 4,353,836	$ -	$ 4,353,836
2008	$ 1.47	3,109,883	$ 4,555,979	$ -	$ 4,555,979
2009	$ 1.53	3,109,883	$ 4,758,121	$ -	$ 4,758,121
2010	$ 1.60	3,109,883	$ 4,960,263	$ -	$ 4,960,263
2011	$ 1.66	3,109,883	$ 5,162,406	$ -	$ 5,162,406
2012	$ 1.73	3,109,883	$ 5,364,548	$ -	$ 5,364,548
2013	$ 1.79	3,109,883	$ 5,566,691	$ -	$ 5,566,691
2014	$ 1.86	3,109,883	$ 5,768,833	$ -	$ 5,768,833
2015	$ 1.92	3,109,883	$ 5,970,975	$ -	$ 5,970,975
2016	$ 1.99	3,109,883	$ 6,173,118	$ -	$ 6,173,118
2017	$ 2.05	3,109,883	$ 6,375,260	$ -	$ 6,375,260
2018	$ 2.12	3,109,883	$ 6,577,403	$ -	$ 6,577,403
2019	$ 2.18	3,109,883	$ 6,779,545	$ -	$ 6,779,545
2020	$ 2.25	3,109,883	$ 6,981,687	$ -	$ 6,981,687

Gross Costs. Total annual costs were calculated by multiplying the expected annual cost increase by the estimated future consumption. Annual fuel consumption of

the U-2 is a sensitive subject due to security reasons. Although the Air Force's annual consumption of JPTS is unclassified, data for the last five years was unavailable. However, consumption data was available for 1999 (3,180,188 gallons) and 2000 (3,039,578) (Westhausen). According to the source of the data and other experts in the field, the annual JPTS consumption is not expected to increase. The average consumption of 1999 and 2000 (3,109,853 gallons) was used in this study as the expected annual fuel consumption of the U-2.

Table 22. Estimated JPTS Annual Gross Costs
(Based on a $0.14 annual price increase and no annual consumption increase)

Year	Estimated Price per gallon	Estimated consumption	Estimated Annual Gross Cost	Startup Costs	Total Annual Gross Cost
2001	$ 3.25	3,109,883	$ 10,107,120	$ -	$ 10,107,120
2002	$ 3.39	3,109,883	$ 10,542,503	$ -	$ 10,542,503
2003	$ 3.53	3,109,883	$ 10,977,887	$ -	$ 10,977,887
2004	$ 3.67	3,109,883	$ 11,413,271	$ -	$ 11,413,271
2005	$ 3.81	3,109,883	$ 11,848,654	$ -	$ 11,848,654
2006	$ 3.95	3,109,883	$ 12,284,038	$ -	$ 12,284,038
2007	$ 4.09	3,109,883	$ 12,719,421	$ -	$ 12,719,421
2008	$ 4.23	3,109,883	$ 13,154,805	$ -	$ 13,154,805
2009	$ 4.37	3,109,883	$ 13,590,189	$ -	$ 13,590,189
2010	$ 4.51	3,109,883	$ 14,025,572	$ -	$ 14,025,572
2011	$ 4.65	3,109,883	$ 14,460,956	$ -	$ 14,460,956
2012	$ 4.79	3,109,883	$ 14,896,340	$ -	$ 14,896,340
2013	$ 4.93	3,109,883	$ 15,331,723	$ -	$ 15,331,723
2014	$ 5.07	3,109,883	$ 15,767,107	$ -	$ 15,767,107
2015	$ 5.21	3,109,883	$ 16,202,490	$ -	$ 16,202,490
2016	$ 5.35	3,109,883	$ 16,637,874	$ -	$ 16,637,874
2017	$ 5.49	3,109,883	$ 17,073,258	$ -	$ 17,073,258
2018	$ 5.63	3,109,883	$ 17,508,641	$ -	$ 17,508,641
2019	$ 5.77	3,109,883	$ 17,944,025	$ -	$ 17,944,025
2020	$ 5.91	3,109,883	$ 18,379,409	$ -	$ 18,379,409

The cost of the equipment needed to implement JP8+100LT has been included in the annual cost figures. These values were obtained by estimates made by experts in the POL Tech Team at the Air Force Petroleum Office (Green). Additionally, the expected cost of the additive ($0.005 per gallon) has been included in the calculations. The values in Tables 21 and 22 reflect gross values without regard to inflation. Discounting future costs is addressed next.

Table 23. JP-8+100LT Annual Discounted Costs

Year	Annual Gross Cost	Discount Factor	Annual Discounted Cost	Total Cumulative Discounted Costs
2001	$ 3,440,982	0.9667	$ 3,326,523	$ 3,326,523
2002	$ 3,643,124	0.9035	$ 3,291,534	$ 6,618,056
2003	$ 3,845,267	0.8444	$ 3,246,886	$ 9,864,942
2004	$ 3,947,409	0.7891	$ 3,115,078	$ 12,980,020
2005	$ 3,949,551	0.7375	$ 2,912,868	$ 15,892,888
2006	$ 4,151,694	0.6893	$ 2,861,637	$ 18,754,525
2007	$ 4,353,836	0.6442	$ 2,804,643	$ 21,559,168
2008	$ 4,555,979	0.6020	$ 2,742,858	$ 24,302,026
2009	$ 4,758,121	0.5626	$ 2,677,154	$ 26,979,180
2010	$ 4,960,263	0.5258	$ 2,608,308	$ 29,587,488
2011	$ 5,162,406	0.4914	$ 2,537,012	$ 32,124,499
2012	$ 5,364,548	0.4593	$ 2,463,881	$ 34,588,380
2013	$ 5,566,691	0.4292	$ 2,389,461	$ 36,977,841
2014	$ 5,768,833	0.4012	$ 2,314,232	$ 39,292,073
2015	$ 5,970,975	0.3749	$ 2,238,621	$ 41,530,694
2016	$ 6,173,118	0.3504	$ 2,162,997	$ 43,693,691
2017	$ 6,375,260	0.3275	$ 2,087,688	$ 45,781,379
2018	$ 6,577,403	0.3060	$ 2,012,975	$ 47,794,354
2019	$ 6,779,545	0.2860	$ 1,939,102	$ 49,733,456
2020	$ 6,981,687	0.2673	$ 1,866,280	$ 51,599,735

Discounted Costs. The annual cost figures from the tables above were then converted to net present value by discounting using a 4.1 percent expected annual inflation rate. The resulting values represent the fugues used in this study for the overall cost calculations. The interest rate of 4.1 percent was chosen in accordance with guidance set forth in the Office of Management and Budget's Circular No. A-94, Revised: Guidelines and Discount Rates for Benefit-Cost Analysis of federal Programs.

The data in Tables 23 and 24 answer investigative question 3 and 4. These data show that JP-8+100LT is clearly less costly that JPTS.

Table 24. JPTS Annual Discounted Costs

Year	Annual Gross Cost	Discount Factor	Annual Discounted Cost	Total Cumulative Discounted Costs
2001	$10,107,120	0.9667	$ 9,770,921	$ 9,770,921
2002	$10,542,503	0.9035	$ 9,525,068	$ 19,295,989
2003	$10,977,887	0.8444	$ 9,269,564	$ 28,565,553
2004	$11,413,271	0.7891	$ 9,006,725	$ 37,572,278
2005	$11,848,654	0.7375	$ 8,738,603	$ 46,310,882
2006	$12,284,038	0.6893	$ 8,467,016	$ 54,777,897
2007	$12,719,421	0.6442	$ 8,193,563	$ 62,971,461
2008	$13,154,805	0.6020	$ 7,919,652	$ 70,891,112
2009	$13,590,189	0.5626	$ 7,646,512	$ 78,537,624
2010	$14,025,572	0.5258	$ 7,375,215	$ 85,912,840
2011	$14,460,956	0.4914	$ 7,106,689	$ 93,019,529
2012	$14,896,340	0.4593	$ 6,841,733	$ 99,861,262
2013	$15,331,723	0.4292	$ 6,581,028	$ 106,442,290
2014	$15,767,107	0.4012	$ 6,325,153	$ 112,767,443
2015	$16,202,490	0.3749	$ 6,074,590	$ 118,842,033
2016	$16,637,874	0.3504	$ 5,829,741	$ 124,671,774
2017	$17,073,258	0.3275	$ 5,590,930	$ 130,262,705
2018	$17,508,641	0.3060	$ 5,358,415	$ 135,621,119
2019	$17,944,025	0.2860	$ 5,132,394	$ 140,753,513
2020	$18,379,409	0.2673	$ 4,913,012	$ 145,666,526

Cost Benefit Analysis

So far, JP-8+100LT has been shown to posses more logistical benefits while being less costly. Hence, it would follow that JP-8+100LT would outperform JPTS in a cost benefit analysis. The following section confirms this.

Relative Benefit Comparison. Table 25 presents a summary of the benefits and costs of each fuel for the periods of five, ten, and twenty years. This chart serves as a visual reference of the answers to investigative question 1 through 4: JP-8+100LT has a significantly higher Benefit Rating with an annual discounted cost less than one third of that of JPTS.

Table 25. Relative Benefit Comparison

Fuel	Cumulative Discounted Cost (CDC)	Benefit Rating (BR)
5 Years		
JP-8+100LT	$ 15,892,888	2.66
JPTS	$ 46,310,882	2.00
10 Years		
JP-8+100LT	$ 29,587,488	2.66
JPTS	$ 85,912,840	2.00
20 Years		
JP-8+100LT	$ 51,599,735	2.66
JPTS	$ 145,666,526	2.00

Relative Value Comparison. A benefit to cost ratio was also performed to further demonstrate relative value. Benefits and costs were converted into common values to enable the calculation as shown in Table 26.

Table 26. Cost-Benefit Analysis Conversion Table

Fuel	Cumulative Discounted Cost (CDC)	Conversion factor 1/100000 (CF1)	Converted Cost (CC) *CDC*CF1*	Benefit Rating (BR)	Conversion factor 100 (CF2)	Converted Benefit (CB) *BR*CF2*
5 Years						
JP-8+100LT	$ 15,892,888	0.000001	15.89	2.66	10	26.63
JPTS	$ 46,310,882	0.000001	46.31	2.00	10	20.00
10 Years						
JP-8+100LT	$ 29,587,488	0.000001	29.59	2.66	10	26.63
JPTS	$ 85,912,840	0.000001	85.91	2.00	10	20.00
20 Years						
JP-8+100LT	$ 51,599,735	0.000001	51.60	2.66	10	26.63
JPTS	$ 145,666,526	0.000001	145.67	2.00	10	20.00

After converted costs and benefits to common values, a Benefit to Cost Ratio (BCR) was calculated as shown in Table 27. JP8+100LT has higher BCR for each time period indicating a higher relative value in terms of benefits and cost.

Table 27. Relative Value Comparison

Fuel	Converted Cost (CC)	Converted Benefit (CB)	Benefit To Cost Ratio *CB/CC* (BCR)	Percent BCR Improvement
5 Years				
JP-8+100LT	15.89	26.63	1.68	388%
JPTS	46.31	20.00	0.43	-
10 Years				
JP-8+100LT	29.59	26.63	0.90	387%
JPTS	85.91	20.00	0.23	-
20 Years				
JP-8+100LT	51.60	26.63	0.52	376%
JPTS	145.67	20.00	0.14	-

Summary

The data presented in this chapter answers the investigative questions introduced in Chapter 1. Specifically, the data show that JP-8+100LT provides more benefits while costing less than a third of JPTS. Summaries of the benefits, costs, and cost benefit analysis are presented in Figures 2 and 3.

Table 28. Benefits Summary

Average Survey Scores (AC)

Availability	Handling	Resources Required	Operational Efficiency
3.3810	2.8571	2.0476	2.3333

Average Survey Weights (AW)

Availability	Handling	Resources Required	Operational Efficiency
0.2976	0.2048	0.3143	0.1833

Weighted Scores

Benefit	Average Score (AC)	Average Weight (AW)	Weighted Scores (AC)*(AW)
JP-8+100LT			
Availability	3.38	0.298	1.006
Handling	2.86	0.205	0.585
Resources Required	2.05	0.314	0.644
Operational Efficiency	2.33	0.183	0.428
JPTS			
Availability	2.00	0.298	0.595
Handling	2.00	0.205	0.410
Resources Required	2.00	0.314	0.629
Operational Efficiency	2.00	0.183	0.367

Overall Benefit Ratings (BR)

Fuel	Availability Weighted Score	Handling Weighted Score	Resources Weighted Score	Operations Weighted Score	Overall Benefit Rating (BR)
JP-8+100LT	1.006	0.585	0.644	0.428	2.663
JPTS	0.595	0.410	0.629	0.367	2.000

Table 29. Costs and Cost Benefit Analysis Summary

Costs Summary

Fuel	Cumulative Gross Costs	Cumulative Discounted Costs
5 Years		
JP-8+100LT	$ 18,826,333	$ 15,892,888
JPTS	$ 54,889,435	$ 46,310,882
10 Years		
JP-8+100LT	$ 41,606,226	$ 29,587,488
JPTS	$ 120,663,460	$ 85,912,840
20 Years		
JP-8+100LT	$ 102,326,692	$ 51,599,735
JPTS	$ 284,865,283	$ 145,666,526

Relative Benefit Comparison

Fuel	Cumulative Discounted Costs	Benefit Rating (BR)
5 Years		
JP-8+100LT	$ 15,892,888	2.66
JPTS	$ 46,310,882	2.00
10 Years		
JP-8+100LT	$ 29,587,488	2.66
JPTS	$ 85,912,840	2.00
20 Years		
JP-8+100LT	$ 51,599,735	2.66
JPTS	$ 145,666,526	2.00

Cost to Benefit Ratio

Fuel	Converted Cost (CC)	Converted Benefit (CB)	Benefit To Cost Ratio CB/CC	Percent Improvement
5 Years				
JP-8+100LT	15.89	26.63	1.68	388%
JPTS	46.31	20.00	0.43	-
10 Years				
JP-8+100LT	29.59	26.63	0.90	387%
JPTS	85.91	20.00	0.23	-
20 Years				
JP-8+100LT	51.60	26.63	0.52	376%
JPTS	145.67	20.00	0.14	-

V. CONCLUSIONS

Introduction

This Chapter discusses the analysis presented in Chapter 4. Chapter 5 will begin a review of the background of this study followed by recommendations based on the preceding analysis.

Summary

The development of the U-2 in the mid-fifties created a need for specialized fuel. The U-2 demanded a fuel that could meet the demands of its unique operating environment. JPTS was designed to meet this demand. The U-2 places demands on its fuel at both ends of the temperature spectrum. The U-2's long missions complicate this process. In order for the U-2 to complete the 9-hour or longer missions, it must conserve fuel. The restricted fuel flow exposes smaller amounts of fuel to extreme heat and stress. To keep the fuel form breaking down under this heat and pressure, the fuel must have a high degree of thermal stability. JPTS has an upper heat rating of 425 degrees Fahrenheit. This is 100 degrees higher than the Air Force's current fuel, JP-8 whose upper fuel rating is 325 degrees Fahrenheit.

The U-2 also places extremely low temperature demands on its fuel. The U-2's fuel must withstand the temperatures it is exposed to at the aircraft's operating altitudes. The fuel must be capable of withstanding temperatures as low as –53 degrees Celsius. This is 6 degrees Celsius lower than Air Force's current fuel, JP-8, whose lower fuel

rating is –47 degrees Celsius. This is a critical difference in temperature. This 6-degree difference is the difference between the fuel being a liquid or a solid.

Although the U-2's demand for a high performance fuel has not been eliminated, the Air Force's alternatives for meeting this demand have changed since the 1950's. The primary alternative is through the use of fuel additives. In 1989, the Air Force Research Laboratory began a program of evaluating additives as a means of reducing fouling deposits in engines and fuel systems. When JP-8 is injected with this additive, the result is known as JP-8+100. The new fuel contains a detergent and a dispersant to prevent fuel from gumming up on engine components, and a metal deactivator. The additive also increases the thermal stability of the fuel from 325 degrees to 425 degrees Fahrenheit, hence the name +100. This increased thermal stability is essential for both current and future Air Force weapon systems including the U-2.

The JP-8+100 fuel meets the high-end temperature requirements for the U-2. This raised the question of the capability to use JP-8+100 as a replacement for JPTS. The cost of JP-8 is less than a third of the cost of JPTS and is readily available. Only two specialty refineries manufacture JPTS. JP-8 is available from most oil refineries worldwide. However, JP-8+100 does not meet the low temperature requirements of the U-2.

Additives have now been developed which would enable JP-8+100 to meet the low temperature requirements. The fuel resulting from injecting the low temperature additive is known as JP-8+100LT (LT for low temperature). JP-8+100LT could replace JPTS. With an added cost of only $0.005 per gallon over JP-8, JP-8+100LT has the potential for great savings in fuel costs.

Recommendation

According to surveys taken by experts in the fuels community, JP-8+100LT offers significant logistical advantages. As shown in Table 17, the benefits offered by JP-8+100LT may be considered only marginal in the areas of Resources and Operations. However, significant benefits seem to be available in the areas of Availability and Handling. Additionally, the cost analysis revealed that converting from JPTS to JP-8+100LT represents potential savings of approximately $5 million annually. The fact that additive-enhanced JP-8 outperforms JPTS in both benefits and costs, makes it the clear winner in this study. It seems clear that JP-8+100LT is a suitable replacement for JPTS as the primary fuel for the U2 aircraft in the new millennium.

Contributions of Research

Prior to this study, no documented case of quantifying fuel-related benefits was available. Additionally, no comprehensive comparison of the costs and benefits of differing fuel systems had been documented. This work provides the Air Force with a tool for quantifying benefits and comparing benefits and costs for future fuel conversion decisions.

Appendix A: Conversion Survey

Part 1: Rate the impact of a conversion
Tell us how you think a conversion would affect the following areas.

Choose the statement that best describes the probable conversion outcome in the following areas.

Fuel Availability (Consider factors such as short-notice availability, availability of fuel in remote locations, and shipping time of fuel orders.)

A. Conversion offers a significant improvement

B. Conversion offers a slight improvement

C. Conversion offers no foreseeable change or is unknown

D. Conversion offers a slight degradation

E. Conversion offers a significant degradation

Click inside the box and type your answer (A-E) >>>

Fuel Handling (Consider factors such as the ease of storing, the ease of transporting, and the ease and accuracy of accounting.)

A. Conversion offers a significant improvement

B. Conversion offers a slight improvement

C. Conversion offers no foreseeable change or is unknown

D. Conversion offers a slight degradation

E. Conversion offers a significant degradation

Click inside the box and type your answer (A-E) >>>

Resources Required (Consider the long-term requirement of personnel, facilities, and equipment for operations and training.)

A. Conversion requires significantly fewer resources

B. Conversion requires slightly fewer resources

C. Conversion requires no foreseeable change in resources

D. Conversion requires slightly more resources

E. Conversion requires significantly more resources

Click inside the box and type your answer (A-E) >>>

Refueling Operations (Consider factors such as ease and accuracy of Quality Control, efficiency of refueling, and ease of handling defuels.)

A. Conversion offers a significant improvement

B. Conversion offers a slight improvement

C. Conversion offers no foreseeable change or is unknown

D. Conversion offers a slight degradation

E. Conversion offers a significant degradation

Click inside the box and type your answer (A-E) >>>

Part 2: Rank the logistics categories

Tell us the relative importance of the following categories when comparing JPTS to additive-enhanced JP-8.

Allocate 100 percent among the four categories below to reflect their relative importance.

Example:	Fuel Availability	25%
	Fuel Handling	25%
	Resources Requirements	25%
	Refueling Operations	25%

Enter your allocated values below. *Please ensure the four values add up to 100.*

Fuel Availability		%
Fuel Handling		%
Resources Requirements		%
Refueling Operations		%

Part 3: Overall Assessment

Do you believe that replacing JPTS with additive-enhanced JP-8 would be beneficial to the Air Force? (Type an "X" in the appropriate box below)

☐ Yes

☐ No

Why or why not? Please provide your comments below.

What potential benefits do you foresee as a result of a conversion?

What potential problems do you foresee as a result of a conversion?

Appendix B: Survey Score Results

Appendix B. Survey Scores			
Availability	**Handling**	**Resources Required**	**Operational Efficiency**
Individual Score Ratings			
4	2	1	2
2	3	2	2
4	4	3	1
4	4	3	4
4	2	1	2
3	2	2	1
4	4	2	2
2	2	2	2
3	2	2	3
3	2	2	2
4	2	3	3
2	2	2	1
3	4	2	3
3	4	2	3
3	2	1	4
4	3	3	2
4	4	2	2
4	2	2	1
4	4	1	4
4	3	2	2
3	3	3	3
Average Scores			
3.3810	2.8571	2.0476	2.3333

Appendix C: Survey Weight Results

Appendix C. Survey Weights			
Availability	Handling	Resources Required	Operational Efficiency
0.15	0.2	0.5	0.15
0.4	0.25	0.2	0.15
0.5	0.25	0.1	0.15
0.4	0.2	0.2	0.2
0.15	0.2	0.5	0.15
0	0.2	0.5	0.3
0.5	0.1	0.25	0.15
0.25	0.25	0.25	0.25
0.3	0.2	0.3	0.2
0.25	0.3	0.3	0.15
0.25	0.25	0.3	0.2
0.3	0.1	0.3	0.3
0.35	0.15	0.35	0.15
0.4	0.2	0.1	0.3
0.25	0.2	0.35	0.2
0.3	0.25	0.35	0.1
0.2	0.25	0.4	0.15
0.3	0.2	0.3	0.2
0.25	0.25	0.4	0.1
0.4	0.1	0.3	0.2
0.35	0.2	0.35	0.1
Average Weights			
0.2976	0.2048	0.3143	0.1833

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14. ABSTRACT
The Air Force currently spends approximately $10 million dollars annually on fuel support for the U-2 aircraft. The U-2 has used a jet fuel known as JPTS since the aircraft's development in the 1950's. JPTS is a specialty fuel used only by the U-2 and is produced by two oil refineries in the United States. As such, it has limited worldwide availability and costs over three times the per-gallon price of the Air Force's primary jet fuel, JP-8.

Recent research performed at the Air Force Research Laboratory Propulsion Directorate suggests that additives could be added to JP-8, which would make it a suitable low-coast replacement for JPTS. The additive-enhanced fuel has come to be known as JP-8+100LT.

This study analyzed two variables, logistics benefits and costs, and compared these variables for JPTS and JP-8+100LT to discover which one provides the most logistical benefits for the annual cost. The results of the analysis concluded that JP-8+100LT offers more benefits at significant cost savings.

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